IRC:SP:139-2023

GUIDELINES FOR HIGH PERFORMANCE BITUMINOUS MIXES FOR HIGH VOLUME ROADS

INDIAN ROADS CONGRESS
2023

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Published by:

INDIAN ROADS CONGRESS

Kama Koti Marg,
Sector-6, R.K. Puram,
New Delhi-110 022

DECEMBER, 2023

Price : ₹ 500/-
(Plus Packing & Postage)

IRC:SP:139-2023

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Author's Name
Indian Roads Congress

Published by
Indian Roads Congress

Publisher's Address
Kama Koti Marg, Sector-6, R.K. Puram, New Delhi-110 022

Printer's Details
Royal Press, B-81, Okhla Indl. Area, Phase-1, New Delhi-110 020

Edition Details
First Published, December, 2023

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GUIDELINES FOR HIGH PERFORMANCE BITUMINOUS MIXES FOR HIGH VOLUME ROADS

1. GENERAL

Most of the Indian Highways have bituminous layers which are subjected to high traffic volumes and severe climatic conditions. For high design traffic volumes and severe climatic conditions, it is essential to adopt binders and mixes which are capable of performing better than the conventional refinery produced binders and dense graded mixes. Several efforts were made in the past for the development of binders and bituminous mixes with improved performance. While the bituminous mixes prepared using stiff unmodified binders may offer higher rutting resistance, they may exhibit less flexibility and consequently have less resistance to cracking. On the other hand, bituminous mixes designed with softer grade unmodified binders tend to demonstrate better fatigue resistance but may be less effective in resisting rutting. For enhanced fatigue and rutting resistance, mixes can be prepared using modified binders or unmodified binders of suitable grade and characteristics can be used.

Among the important developments that took place during the past two decades in the selection of binders and mixes for satisfactory fatigue and rutting performance is the development of high modulus asphalt binder and high modulus asphalt mixes or Enrobé à Module Elevé (EME) mixes. The high modulus mixes typically have high stiffness (modulus) values and are designed to have better rutting and fatigue performance compared to conventional bituminous mixes. The High Modulus Asphalt (HiMA) mixes can, therefore, be referred to as High Performance (HiPER) Bituminous Mixes. These were adopted initially in France and subsequently in other countries. In our country also need was felt for indigenous R&D study to develop hard grade binders and HiMA mixes in laboratory and its evaluation in field performance. Therefore NHAI awarded a Research Scheme to IIT Kharagpur with objective to investigate the suitability of a refinery produced Hard Grade Binder (HB) for the production of HiMA Mixes under guidance of Late Prof. B.B. Pandey. The outcome of NHAI sponsored R&D work on "Hard Grade Binders and HiMA Mixes" was considered by Flexible Pavement Committee of IRC (H-2) during its meeting held on 07.01.2023 when it was decided to prepare guidelines on the subject and requested IIT Kharagpur team to prepare initial document. The initial draft on Guidelines for High Performance (HiPER) Bituminous Mixes for High Volume Roads was prepared by sub group comprising Prof. M. Amaranatha Reddy, Prof. K. Sudhakar Reddy & Dr. Baditha Anil Kumar. Research findings of Dr. Goli Arunkumar and other national/international literature on High Modulus Asphalt has been referred while preparing these guidelines.

Considering the popularity of the high modulus or HiPER bituminous mixes in different countries and also the need for performance-based mixes in India especially for high traffic volume roads, the present guidelines have been developed based on international practice and the investigations carried out in the laboratory and on experimental test sections constructed on National Highways in India. The primary purpose of these guidelines is to provide guidance to the agencies intending the use of high-performance bituminous mixes. These guidelines encompass specifications, test methods, mix designs, and construction practices related to the use of high-performance bituminous mixes.

This document presents the guidelines for the design of a class of High Performance (HiPER) bituminous mixes, termed in literature as Enrobé à Module Elevé (EME) mixes, which typically have high modulus values. These mixes were originally developed by the French Public Works Research Institute, Laboratoire Central des Ponts et Chaussées (LCPC) in 1980 for use in bituminous base courses. This concept was later embraced by other countries and is the main basis for the development of the current guidelines. EME mixes typically use a hard grade binder and dense aggregate gradation and are designed with low air void content (3%). EME/HiPER bituminous mixes are expected to have high modulus values and improved fatigue, rutting and moisture damage resistance.

The High Modulus Asphalt (HiMA) mixes can, therefore, be referred to as High Performance (HiPER) Bituminous Mixes. The terms high modulus and high performance have been used synonymously in these guidelines.

The draft prepared by the subgroup was deliberated in various meetings of H-2 Committee and was finalized in the meeting held on 9th June, 2023 and recommended for placing to Highways Specifications and Standards (HSS) Committee. The document was discussed by the HSS Committee during its meeting held on 27th June, 2023. The Committee approved this draft subject to the incorporation of the written and verbal comments received and for submitting the revised draft to the Executive Committee (EC) and Council. The EC in its meeting held on 6th July, 2023 approved the draft for placing before the Council. The 225th Mid-Term Council in its meeting held on 7th July, 2023 at Raipur (Chhattisgarh) considered and approved draft "Guidelines for High Performance (HiPER) Bituminous Mixes for High Volume Roads" for printing.

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The primary purpose of these guidelines is to provide guidance to the agencies intending the use of high-performance bituminous mixes. These guidelines encompass specifications, test methods, mix designs, and construction practices related to the use of high-performance bituminous mixes.

2. BACKGROUND

Available international experience indicates that High Modulus Asphalt (HiMA) mixes prepared with stiff binders i.e., hard grade paving binders (high performance binders) can perform satisfactorily under severe traffic and climatic conditions (Serfass et al.,1996, Corte 2001, Sanders and Nunn 2005, Dias et al., 2017). These binders typically have penetration value in the range of 10 to 25 at 25°C. The mixes produced with these binders are standardized under the name of "Enrobé à Module Elevé (EME)" for use in bituminous base course. In the 1980's, the French Public Works Research Institute, Laboratoire Central des Ponts et Chaussées (LCPC), developed EME mixes with the aim of improving the mechanical properties and performance of bituminous mixes. The distinctive feature of the HiMA mixes is the use of higher content of hard paving grade bitumen which increases the resistance to fatigue cracking and rutting. These mixes are characterized by high stiffness/modulus, high durability, superior resistance to permanent deformation and fatigue cracking. International experience suggests that significant reduction in the thicknesses of the pavement layers can be achieved using these mixes due to their high stiffness and improved fatigue and rutting performance (Brosseaud et al., 2012; Moreno et al., 2014; and Hernández 2015, Goli et al., 2021, Baditha, 2023). These mixes are appropriate for use in heavy duty pavements carrying high traffic volumes such as Expressways, National Highways and State Highways.

Indian Institute of Technology (IIT) Kharagpur examined the feasibility of adopting the HiMA mix specifications in India and carried out extensive research work for nearly about six years on the "Development of High Modulus Asphalt Mixes for Indian Highways" under a research scheme sponsored by National Highways Authority of India (NHAI) during 2016-2022. As a part of this study, high modulus/High Performance Binders (HiPB) were developed in the laboratory and the performance of the bituminous mixes prepared using these high performance binders was evaluated. The binders used in the study are: (i) a hard grade binder obtained from refinery, produced using Propane De-Asphalting method (PDA), and (ii) single and composite polymer modified binders developed in the laboratory. In the Propane De-Asphalting (PDA) method, a high viscous PDA pitch is treated with propane to extract heavier oils. This PDA pitch contains larger proportions of asphaltenes and resins (Corbett 1984) and has low penetration and high viscosity (Ishai and Tuffour 1987). The penetration and viscosity values of the pitch vary with the source of the crude oil. In order to produce binders of specified requirements, PDA pitch is blended with heavier oils extracted from the crude (Chakkoth et al., 2017).

HiPER bituminous mixes were prepared in the laboratory of IIT Kharagpur using two types of aggregate gradations, namely HiPER gradation-I (Dense Bituminous Macadam-II (DBM-II)) and HiPER gradation-II (Enrobé à Module Elevé-EME2 gradation, Sanders and Nunn 2005). DBM gradation- II is the most used aggregate gradation for the construction of bituminous base layers in India (MoRTH Specifications). The EME2 aggregate gradation was adopted from international specifications available for high performance/high modulus mixes. The Nominal Maximum Aggregate Sizes (NMAS) of HiPER-I (DBM-II) and HiPER-2 (EME2) gradations are 26.5 mm and 19 mm, respectively. With the selected binders and aggregate gradations, bituminous mixes were prepared in the laboratory and evaluated for their performance. The mix design was carried out using Marshall method of mix design and the design binder contents were selected corresponding to an air void content of 3%. Selection of 3% as the design air void content entails use of higher binder contents than the binder contents used for mixes designed for 4% air void content. The bituminous mixes prepared using design binder contents were evaluated in terms of Marshall test parameters (volumetrics, stability and flow) and Indirect Tensile Strength (ITS) and resilient modulus (M_r). The performance of the mixes was evaluated by conducting rutting, fatigue and moisture damage tests. The compactability (workability) of the mixes wasevaluated using gyratory compactor.

Two test sections (with HiPER bituminous mixes used in the base course layer) were constructed on two different National Highways (NH18 & NH49) with the best performing high modulus asphalt/HiPER bituminous mixes identified based on the laboratory mix performance. These test sections were evaluated for their structural and function performance for nearly five years. The salient features of the test sections constructed using these bituminous mixes are presented in **Annexure-A** of these guidelines. Complete details about the laboratory and field investigations carried out by IIT Kharagpur for the NHAI sponsored research project can be found in the 'Final report' submitted to NHAI. The results from the investigations carried out in the laboratory and field were used in formulating the current guidelines.

Considering that the high modulus asphalt binder and mix specifications developed by LCPC, France (Delorme et al., 2007) have been widely calibrated and adopted by different countries, it was decided to adopt the same design framework of specifications for India too. The binder specifications recommended by LCPC were adopted after validating them with the binder properties obtained in the present study. The specifications for high modulus/HiPER bituminous mixes were established based on comparison of the laboratory performance test results obtained for the mixes investigated in the NHAI sponsored research project executed by IIT Kharagpur with the widely calibrated specifications of high modulus asphalt mixes used worldwide **(Annexure-B)**. For the parameters adopted by the international agencies but not commonly used in India, suitable specifications were identified for the corresponding performance tests used in India.

3. SCOPE OF THE GUIDELINES

These guidelines contain the binder and aggregate gradation requirements for producing High Performance (HiPER) bituminous mixes, the mix design methodology and performance requirements. These guidelines provide a modified fatigue performance equation essential for the structural design of pavements using HiPER bituminous mixes. The guidelines also cover construction operations and controls, particularly for the construction of HiPER bituminous mix layers, intended for base and binder courses in flexible pavements on high volume roads. The work shall consist of the construction, in single/ multiple layers, of HiPER bituminous mix as a base/binder course on a previously prepared granular base or existing bituminous layer.

The binders used to produce HiPER bituminous mixes are denoted in these guidelines as hard grade binders or High Performance Binders (HiPB). In general, HiPER bituminous mixes are designed as rich bitumen mixes, and the bitumen content is selected corresponding to 3% design air void content instead of 4% which is normally adopted for conventional mixes. The mix design approach to be followed for selection of design binder content satisfying the performance and other requirements of HiPER bituminous mixes is discussed in these guidelines. The modified fatigue performance equation to be used for the structural design of pavements with HiPER bituminous mixes, construction operations and controls are discussed in these guidelines.

4. MATERIALS

4.1 Bitumen

The bitumen used for HiPER bituminous mixes shall be hard grade bitumen (stiffer than VG40 grade) obtained either by modification of neat binders or produced in the refinery by Propane De-Asphalting (PDA) method. Single or composite modifiers (more than one modifier) shall be blended in appropriate dosages with VG40 or VG30 grade bitumen for producing hard grade bitumen by modification. Any unmodified or modified binder satisfying the requirements (physical and rheological properties) of high performance binder, as detailed in these guidelines, can be used for HiPER bituminous mixes. The requirements of hard grade bitumen (High Performance binder-HiPB), in terms of physical properties are given in **Table 4.1. Table 4.2** contains the additional requirements to be satisfied by HiPB prepared using modifiers. The binder requirements given in **Tables 4.1** and **4.2** are drawn from the LCPC binder specifications (Delorme et al., 2007) and the relevant Indian Specifications (IS: 15462, 2019) for modified binders.

Table 4.1 Specifications for Physical Properties of High Performance Binder (HiPB)

Requirement	Property	Test Method	Units	Specification
Mid temperature consistency	Penetration @ 25°C	IS 1203	0.1 mm	15 to 25
High temperature consistency	Softening point	IS 1205	°C	55 to 71
	Dynamic viscosity @ 60°C	IS 1206	Pa.s	≥ 550
Resistance to age hardening- Rolling Thin Film Oven (RTFO) test	Mass change	ASTM D 2872-21	%	≤ 0.5
	Softening point after hardening	IS 1205	°C	Minimum 2°C higher than original binder
	Increase in softening point	IS 1205	°C	≤ 8
Construction workability	Kinematic viscosity @135°C	IS 1206 (Part 3)	mm^2/s	≥ 600

Table 4.2 Additional Specifications for HiPB Binders prepared using Modifiers

Requirement	Property	Test Method	Units	Specification
Storage stability	Separation difference in softening point, Maximum	Annex C of IS 15462:2019	°C	≤ 3
Superpave rutting parameter of original binder	G*/sinδ of Min 1.0 kPa with 25 mm plate, 1 mm gap, at 10 rad/s, at temperature	Annex B of IS 15462:2019	°C	≥ 76
Superpave rutting parameter of RTFO binder	G*/sinδ of Min 2.2 kPa with 25 mm plate, 1 mm gap, at 10 rad/s, at temperature	Annex B of IS 15462:2019	°C	≥ 76
Multiple Stress Creep Recovery (MSCR) rutting parameter at 60°C	Non-recoverable creep compliance J_{nr} at 3.2 kPa	Annex D of IS 15462:2019	kPa^{-1}	≤ 0.25

4.2 Coarse Aggregates

The provisions of Clause 505.2.2 of MoRTH Specifications shall apply. The specifications for the physical properties of coarse aggregates for HiPER bituminous mixes are given in **Table 4.3.**

Table 4.3 Specifications for Physical Properties of Coarse Aggregates

Requirement	Property	Test Method	Specification
Cleanliness(dust)	Grain size analysis	IS:2386 Part-I	Max 5% passing 0.075 mm sieve
Particle shape	Combined fakiness and elongation Index value	IS:2386 Part-I	Max 35%
Strength	Los Angeles Abrasion value Aggregate impact value	IS:2386 Part-IV	Max 35% Max 27%
Durability	Soundness with Sodium sulphate with Magnesium sulphate	IS:2386 Part-V	 Max 12% Max 18%
Absorption	Water absorption	IS:2386 Part-III	Max 2%
Stripping	Coating and stripping of bitumen aggregate mix	IS:6241	Minimum retained Coating 95%

4.3 Fine Aggregates

The provisions of Clause 505.2.3 of MoRTH Specifications shall apply.

4.4 Filler

The provisions of Clause 505.2.4 of MoRTH Specifications shall apply. The gradation requirement of mineral filler is given in **Table 4.4.**

Table 4.4 Gradation Requirement for Mineral Filler

IS sieve (mm)	Cumulative % passing by Weight of Total Aggregate
0.600	100
0.300	95-100
0.075	85-100

4.5 Aggregate Gradation and Minimum Binder Content

Aggregate gradations and minimum binder contents for HiPER bituminous mixes shall be as given in **Table 4.5**. The layer thicknesses recommended in **Table 4.5** for the two nominal maximum aggregate sizes of 26.5 mm and 19 mm are based on the current recommendations given in the MoRTH Specifications and need to be modified as and when the MoRTH recommendations for layer thicknesses are modified.

Table 4.5 Aggregate Gradations and Minimum Binder Contents for HiPER Bituminous Mixes

Type of Gradation	HiPER-I#	HiPER-II#
Nominal maximum aggregate size (mm)	26.5	19
Layer thickness (mm)	50-75	50
IS sieve (mm)	Cumulative % passing by weight of total aggregate	
37.5	100	100
26.5	90-100	95-100
19.0	71-95	90-100
13.2	56-80	71-95
9.5	-	-
4.75	38-54	35-61
2.36	28-42	22-40
1.18	-	-
0.6	-	-
0.3	7-21	8-18
0.15	-	-
0.075	2-8	3-9
Min binder content for 3% design air void content (% by wt. of aggregate)	4.9*	5.0*

 # HiPER-I: High performance aggregate gradation(similar to DBM gradation-II of MoRTH, Table 500.10) and
#HiPER-II (similar to EME-II: Enrobé à Module Elevé gradation)
**Correspond to aggregate bulk specific gravity of 2.70. In case aggregate specific gravity is more than 2.70, the minimum binder content can be reduced proportionately subjected to fulfilment of performance requirement of HiPER mixes.*

5. MIX DESIGN AND PERFORMANCE REQUIREMENTS FOR HIGH PERFORMANCE (HiPER) BITUMINOUS MIXES

5.1 Design of High Performance (HiPER) Bituminous Mixes

In general, High Performance (HiPER) bituminous mixes are designed as bitumen rich mixes, and the bitumen content is selected corresponding to 3% design air void content whether laid in single layer or two layers. Marshall method of mix design as per Asphalt Institute Manual MS-2 is recommended for preparation of specimens, their volumetric analysis and measurement of stability and flow. The mixes prepared at design bitumen content (corresponding to 3% design air void) shall be verified for Marshall test parameters and performance requirements as discussed in the next section.

5.2 Requirements of HiPER Bituminous Mixes

Table 5.1 gives Marshall test parameter requirements of High Performance (HiPER) bituminous mixes.

Table 5.1 Specifications for Marshall Test Parameters for HiPER Bituminous Mixes

Property	Test Method	Specification
Stability at 60 °C, kN	ASTM D 6927/ AASHTO T 245	Minimum 15
Voids in mineral aggregate (VMA), %	-	Minimum 13
Voids filled with bitumen (VFB), %	-	70 to 80
Marshall flow, mm	ASTM D 6927/ AASHTO T 245	1.5 to 3.0

High Performance (HiPER) bituminous mixes are designed using a performance-based approach. The bituminous mixes prepared at design bitumen content (corresponding to 3% design air voids) should satisfy the performance requirements of (i) Workability, (ii) Stiffness (resilient modulus- M_r), (iii) Rutting performance, (iv) Fatigue performance, and (v) Moisture damage resistance. The specifications for HiPER bituminous mixes were established based on the comparison of the laboratory performance test results obtained for the mixes investigated in the NHAI sponsored research project executed by IIT Kharagpur (Final report on Development of High Modulus Asphalt Mixes for Indian Highways) with the widely calibrated specifications of HiPER bituminous mixes adopted worldwide **(Annexure-B)**. For the parameters adopted by the international agencies but not commonly used in India, suitable specifications were identified for the corresponding performance tests used in India. The specifications for different performance indicators are given in **Table 5.2.**

Table 5.2 Performance Requirements of HiPER Bituminous Mixes

Property of Mix	Test	Test Method	Specification	Annexure
Workability	Gyratory compactor, air voids after 45 gyrations at compaction temperature	EN-12697-31	≤ 6 %	C
Stiffness	Resilient modulus at 35°C, 1 Hz	ASTM D 4123	≥ 3500 MPa (for modified binders) ≥ 4000 MPa (for unmodified binders)	D
Rutting	Rut depth measured using wheel tracker (small device) at 60°C, after 30,000 cycles	EN 12697-22	≤ 6 mm	E
Fatigue	Indirect Tensile Fatigue Test (ITFT) at 25°C, fatigue life of 10^4 cycles at an initial strain, minimum	EN 12697-24, Annex E	$100x10^{-6}$	F
Moisture damage	Tensile Strength Ratio (TSR)	AASHTO T 283	≥ 80 %	G

Annexures C to G detail the salient features of different test methods recommended in these guidelines for evaluation of HiPER bituminous mixes.

5.3 Job Mix Formula

The provisions of Clause 505.3.3 of MoRTH Specifications shall apply except for mixing and compaction temperatures which are given in **Table 5.3**. The test procedure for determining the mixing and compaction temperatures of binders is given in **Annexure H.**

Table 5.3 Mixing, Laying and Compaction Temperatures

Construction Operation	Temperature Range
Mixing	160°C to 190°C
Laying	Minimum 150°C
Compaction	Minimum 125°C

5.4 Plant Trials - Permissible Variation in Job Mix Formula

The provisions of Clause 505.3.4 of MoRTH Specifications shall apply.

5.5 Laying Trials

The provisions of Clause 505.3.5 of MoRTH Specifications shall apply except the field density requirement. The compacted layers of HiPER bituminous mix shall have a minimum field density equal to or more than 96% (≤ 4% air voids) of theoretical maximum specific gravity (G_{mm}) obtained on the day of laying in accordance with ASTM D 2041.

6. FATIGUE PERFORMANCE EQUATION FOR HIGH PERFORMANCE (HiPER) BITUMINOUS MIXES FOR STRUCTURAL DESIGN OF PAVEMENTS

6.1 Fatigue Performance Equation for HiPER Bituminous Mixes

In the structural design of bituminous pavements, the fatigue performance (life) of conventional bituminous mixes prepared with unmodified binders is estimated using the fatigue performance equation given in IRC:37 guidelines. The fatigue equation to be used for structural design of bituminous pavements with HiPER bituminous mixes used in the base layer needs to be modified to reflect the improved fatigue performance of the HiPER bituminous mixes. For estimating the fatigue life of these mixes, the fatigue life adjustment factor was determined based on the laboratory fatigue performance of HiPER bituminous mixes. The ratios of the laboratory fatigue lives of the HiPER bituminous mixes and those of the conventional DBM-II mixes prepared with VG40 bitumen, determined for different strain levels applied in the range of 100 με to 250 με, were used to select the design fatigue life adjustment factor. The fatigue life adjustment factor obtained in the laboratory varied from 1.46 to 9.78 for different HiPER bituminous mixes. The smaller values of adjustment factor were observed at high strain levels whereas the higher values were observed at low strain levels. For a conservative design approach, a fatigue life adjustment factor of 1.4 is suggested.

Equation 6.1 gives the 90% reliability fatigue performance model adopted in IRC:37. The proposed 90% reliability fatigue equation for HiPER bituminous mixes is given as Equation 6.2.

$$N_f = 0.5161*C*10^{-04}*[1/\epsilon_t]^{3.89}*[1/M_r]^{0.854} \quad \text{Eq (6.1)}$$

$$N_f = F_{af}*0.5161*C*10^{-04}*[1/\epsilon_t]^{3.89}*[1/M_r]^{0.854} \quad \text{Eq (6.2)}$$

Where,

F_{af} = Fatigue life adjustment factor = 1.4 for high performance bituminous mixes

$$C = 10^M,\ M = 4.84*\left(\frac{Vbe}{Va+Vbe} - 0.69\right)$$

V_a = Percent volume of air void in the mix used in the bottom bituminous layer

V_{be} = Percent volume of effective bitumen in the mix used in the bottom bituminous layer

N_f = Fatigue life of bituminous layer (cumulative equivalent number of 80 kN standard axle loads that can be served by the pavement before the critical cracked area of 20 % or more of paved surface area occurs)

ϵ_t = Maximum horizontal tensile strain at the bottom of the bottom bituminous layer (DBM) calculated using linear elastic layered theory by applying standard axle load at the surface of the selected pavement system

M_r = Resilient modulus (MPa) of the bituminous mix used in the bottom bituminous layer at 35°C temperature

6.2 Structural Design of Pavements having HiPER Bituminous Mix Layers

The pavement design of pavements with HiPER bituminous mix layers used in base/binder course shall be carried out as per IRC:37 guidelines or its subsequent version with the following modifications. The fatigue of bituminous layer shall be as per high performance/high modulus bituminous mix fatigue equation (Equation 6.2). The M_r values at 35°C for high performance bituminous mixes with unmodified and modified binders shall be taken as 4000 and 3500 MPa, respectively and the mixes shall satisfy the performance requirements given in **Tables 5.1** and **5.2**. An example for structural design of pavements having HiPER base and binder courses is given in **Annexure I**.

7. CONSTRUCTION OPERATIONS

7.1 Weather and Seasonal Limitations

The provisions of Clause 501.5.1 of MoRTH Specifications shall apply.

7.2 Preparation of Surface of the Supporting Layer

The base on which High Performance (HiPER) bituminous mix material is to be laid shall be prepared in accordance with Clauses 501.8 and 502 of MoRTH Specifications as appropriate, or as directed by the Engineer.

7.3 Tack Coat

Where the material on which the High Performance (HiPER) bituminous mix is to be laid is either bitumen bound layer or primed granular layer, tack coat shall be applied, as specified, in accordance with the provisions of Clause 503 of MoRTH Specifications, or as directed by the Engineer.

7.4 Mixing and Transportation of the Mix

Table 5.3 presents the mixing, laying, and compaction temperatures for high performance (HIPER) bituminous mixes prepared using hard grade bitumen (high performance binders). In the case of modified bitumen, the temperature of mixing and compaction shall be determined as per MS-2 (2015) guidelines. In order to have uniform quality, the plant shall be calibrated from time to time.

7.5 Spreading

The provisions of Clauses 501.5.3 and 501.5.4 of MoRTH Specifications shall apply.

7.6 Compaction

The general provisions of Clauses 501.6 of MoRTH Specifications shall apply, as modified by the approved laying trials. The compaction process shall be carried out by the same plant, and using the same method, as approved in the laying trials, which may be varied only with the approval of the Engineer in writing.

7.7 Opening to Traffic

Traffic shall not be allowed on the surface of high performance base/binder course without the approval of the Engineer in writing until the mix is cooled to the ambient temperature.

7.8 Rate Analysis

Except for the rates of bitumen and bituminous mix heating, the remaining components shall be considered similar to the conventional rate analysis of DBM-II.

8. CONTROLS

8.1 Surface Finish and Quality Control of Work

The surface finish of the completed construction shall conform to the requirements of Clause 902 of MoRTH Specifications. All materials and workmanship shall comply with the provisions set out in Section 900 (Table 900-4: Dense Bituminous Macadam-Binder content, aggregate gradation, stability, flow, air voids, moisture damage and other requirements) of the MoRTH Specifications. The additional tests mentioned in **Table 8.1** are to be carried out on HiPER bituminous mixes for the field quality control.

Table 8.1 Additional Tests for Quality Control of HiPER Bituminous Mixes

Test	Frequency
Indirect Tensile Strength at 35°C should be more than 900 kPa	Three tests for each 400 tonnes of mix subject to minimum of two tests per day per plant

In addition to the above, the following mix performance tests are to be carried out whenever there is change in the quality or source of coarse or fine aggregates.

i. Workability using Gyratory Compactor

ii. Stiffness in terms of Resilient Modulus

iii. Fatigue performance by conducting Indirect Tensile Fatigue Test (ITFT)

iv. Rutting resistance using Wheel Tracker

v. Moisture susceptibility of mix using Tensile Strength Ratio

Frequency: Three replicates for each performance indicator.

Annexure A

Details of the Test Sections constructed using HiPER Bituminous Mixes in Base/Binder Courses for a Research Project carried out by IIT Kharagpur and Sponsored by National Highways Authority of India (NHAI)

Two separate test sections were constructed on two different National Highways (NH18 and NH49) for evaluating the constructability and performance of pavements with HiPER bituminous mix as a base course. The details of the test sections and the observations on different aspects of the test sections are discussed in the following sections.

A.1 Test Section- I on National Highway: NH18

A.1.1 General Description of Test Section on NH18

The first test section, constructed with High Performance (HiPER) bituminous mixes, is a part of Jharpokaria-Baripada-Balasoresection of National Highway -NH18 in the state of Odisha, India. It is a rehabilitation and widening (two lane to four lane) project. The existing two-lane road was strengthened and widened (7.0 m to 9.0 m) on the right-hand side (RHS) and the left-hand side (LHS) carriageway was upgraded with new two-lane jointed plain cement concrete pavement (JPCP). The test section of 1.5 km length, with HiPER bituminous mix in base course layer, was constructed in the RHS carriageway from Km 1+500 to Km 3+000 during February 2018 and May 2018. As per the Detailed Project Report (DPR) of the work, the 15-year design traffic is 64 Million Standard (80 kN) Axle repetitions (msa). As indicated in the DPR, the existing pavement was in good condition (Km 1+500 to Km 3+000) and the average layer thicknesses of the existing bituminous and granular layers are 208 and 476 mm, respectively. The effective design California Bearing Ratio (CBR) of the subgrade was 15%. Out of the 1500 m length of test section, 190 m length was reconstruction stretch and remaining 1310 m length was widening and overlay.

The proposed thicknesses in the reconstruction stretch were 200 mm Granular Sub Base (GSB), 250 mm granular base, 75 mm bituminous base course, and 40 mm wearing course. The proposed thicknesses for the overlay (7.0 m width) for the design traffic of 64 msa were 50 mm base course and 40 mm wearing course. The thicknesses of different layers for the widening portion (2.0 m width) were the same as the thicknesses of reconstruction stretch. **Fig. A.1** shows the typical cross section of National Highway (NH)-18.

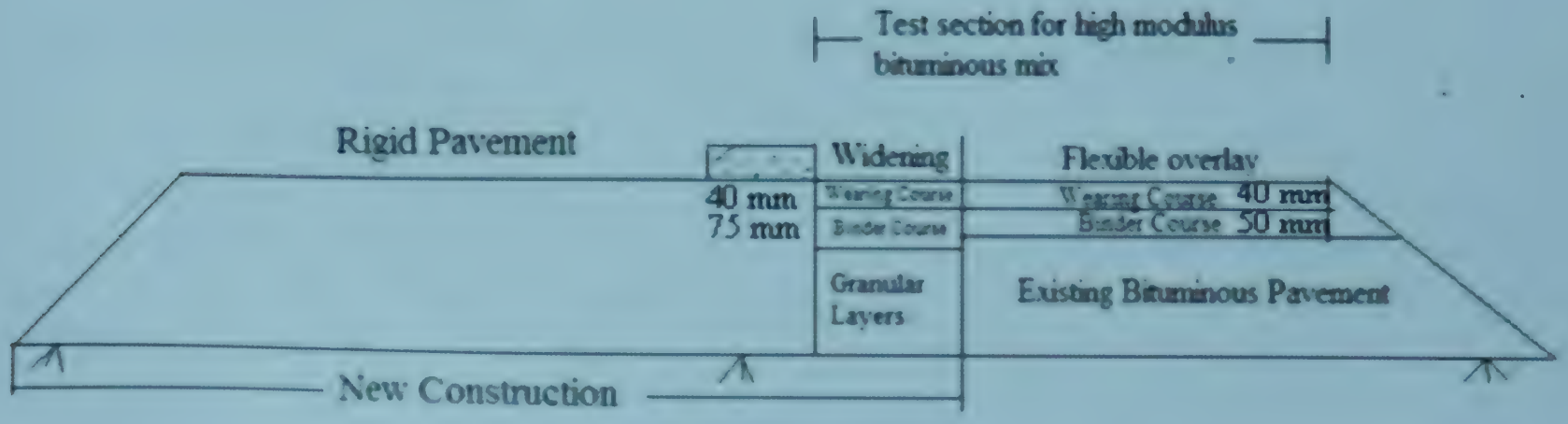

Fig. A.1 Typical Cross Section of NH18 Test Section

A.1.2 Mix Combinations used for NH18 Test Section

The bituminous base course of the test section was constructed with five different types of bituminous mixes prepared with three binders and two aggregate gradations. The binders used were two High Performance Binders (HiPB):- (i) one refinery Hard Binder (HB) produced by PDA process and obtained from Indian Oil Corporation Limited (IOCL) Haldia and (ii) Ethylene Vinyl Acetate (EVA) polymer modified binder produced by modifying VG40 base bitumen with composite EVA polymers. In addition, one conventional binder (VG40) was also used. The aggregate gradations used were (i) HiPER-I (DBM gradation-II of MoRTH Specifications) and (ii) HiPER-II (EME2 gradation). For each of the five types of base course mixes, two types of surface layers which are gap-graded (Stone Matrix Asphalt-SMA and Gap Graded Rubberized Bituminous mix -GGRB), were used. Polymer Modified Bitumen (PMB-40) and Crumb Rubber Modified Binder (CRMB) were used in the SMA and GGRB mixes, respectively. 13 mm Nominal Maximum Aggregate Size (NMAS) gradation recommended in IRC:SP:79 guideline was used for SMA and the gap gradation recommended in IRC:SP:107 guideline was used for GGRB. **Fig. A.2** shows typical layout of NH18 test section.

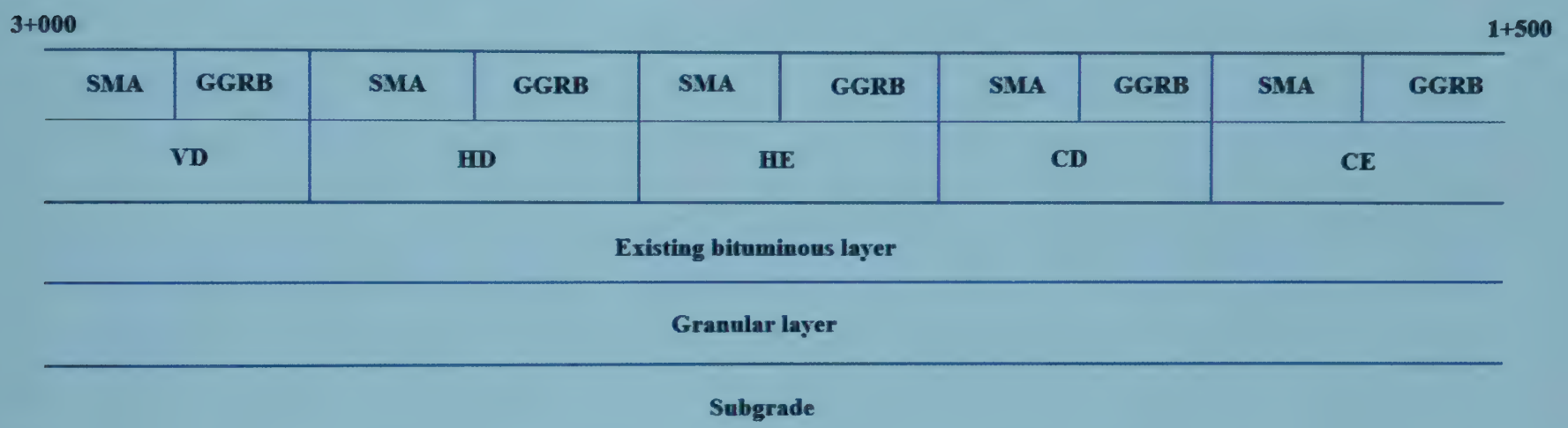

Fig. A.2 Typical Layout of the NH18 Test Section

VD: VG40+DBM-II/HiPER-I; HD: Hard binder + DBM-II(HiPER-I); HE: Hard binder+EME 2(HiPER-II); CD: EVA modified binder +DBM-II (HiPER-I); CE: EVA modified binder (V4E13) +EME 2 (HiPER-II); SMA: Stone Matrix Asphalt; GGRB:Gap Graded Rubberised Bituminous mix

Fig. A.3 shows different views of the test section on NH18.

Fig. A.3 Different Views of the Test Section on NH18

A.2 Test Section on National Highway:NH49

A.2.1 General Description of Test Section on NH49

The second test section of HiPER bituminous mixes was constructed on National Highway-49 (NH-49) in the Baharagora-Singara stretch in the state of Odisha. It was a 2-lane to 4-lane upgradation project. The existing two-lane road was strengthened on the left-hand side (LHS) carriageway and upgraded on the right-hand side (RHS) carriageway with new two-lane flexible pavement. The base bituminous course (high performance bituminous mix) section of 1.8 km length was constructed in the RHS direction between km. 200+960 to km. 202+760 during August 2019 and August 2020. As per the Detailed Project Report (DPR) of the work, the design traffic was 80 million standard axle load (80 kN) repetitions. The effective design California Bearing Ratio (CBR) of the subgrade was 10%. The proposed thicknesses of layers for the new two-lane flexible pavement are 200 mm granular sub base, 250 mm granular base, 115 mm bituminous base course, and 40 mm wearing course. The bituminous mix with HiPER-I (DBM-II) aggregate gradation (MoRTH Specifications) and Viscosity Grade (VG40) binder, was recommended for the base course as per the DPR. It was suggested that DBM be laid in two layers, with the bottom layer being 65 mm thick and the top layer being 50 mm thick. In the wearing course, a bituminous mix with Bituminous Concrete (BC-II) aggregate gradation (MoRTH Specifications) and Viscosity Grade (VG40) binder was recommended.

A.2.2 Mix Combinations used for the NH49 Test Section

The bituminous base course was constructed with five different types of bituminous mixes prepared with two binders and two aggregate gradations. The binders used were hard binder (refinery hard binder HB) and conventional VG40 binder. One of the aggregate gradations used for the base course was HiPER-I (DBM-II of MoRTH Specifications), which is commonly used for the construction of base course of bituminous pavements in India. HiPER-II (EME2 gradation) was the other gradation adopted from the high modulus bituminous mix guidelines of the United Kingdom (Delorme et al. 2007). **Fig. A.4** shows typical layout of NH49 test section. **Fig. A.5** shows different views of NH49 test section.

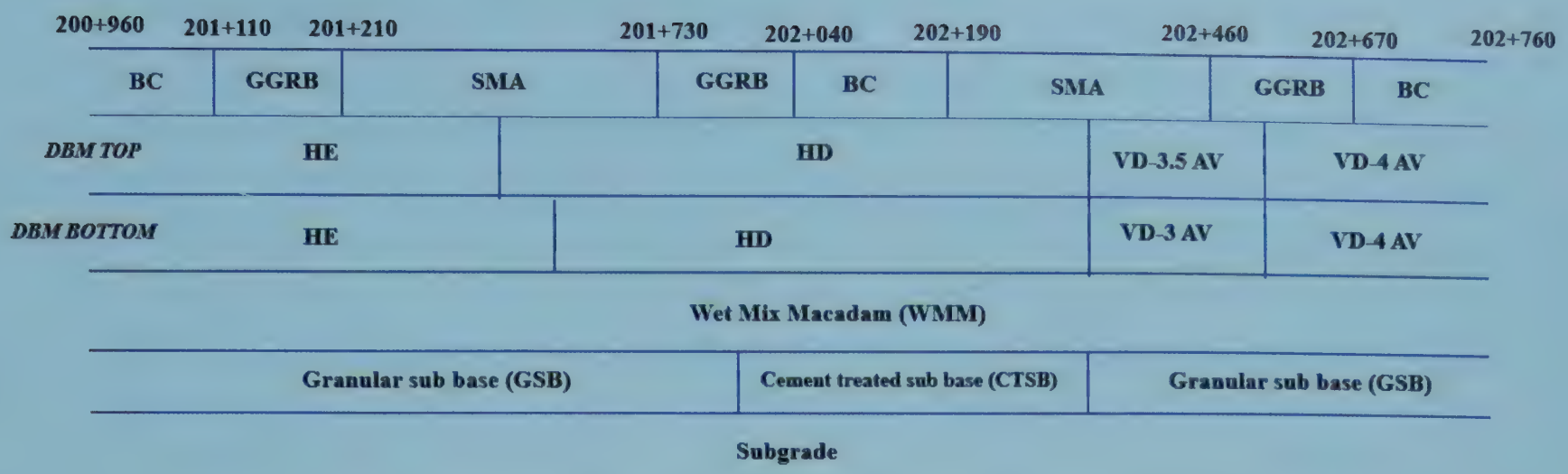

Fig. A.4 Typical Layout of the NH49 Test Section

HD: Hard binder + DBM-II/HiPER-I mix; HE: Hard binder+EME2/HiPER-II mix; VD- 3AV: VG40+DBM-II mix (HiPER-I) (3% design air voids); VD-3.5AV -VG40+DBM-II /HiPER-I mix (3.5% design air voids); VD-4AV : VG40+DBM-II / HiPER-I mix (4% design air voids); BC: Bituminous concrete: SMA: Stone Matrix Asphalt, GGRB: Gap Graded Rubberised Bituminous mix

Fig. A.5 Different Views of NH49 Test Section

A.3 Typical Properties of HiPER Bituminous Mixes used in the Construction of Test Sections

Marshall test parameters and performance test results of the HiPER bituminous mixes used in the construction of NH18 test section are given **Tables A.1** and **A.2** for reference. Similarly, the HiPER bituminous mixes used in NH49 test section satisfied the specifications given in these guidelines.

Table A.1 Marshall Test Parameters of HiPER Bituminous Mixes used in NH18

Properties	Mix type				Requirement
	HD	HE	CD	CE	
Design air voids (%)	3.0	3.0	3.0	3.0	3.0
Design binder content (%)	5.2	5.3	5.2	5.3	Minimum 4.9% for HiPER-I/ DBM-II Minimum 5.0% for HiPER-II/ EME2
% Voids in Mineral Aggregate (VMA)	13.0	13.7	13.8	14.1	Minimum 13.0
% Voids Filled with Bitumen (VFB)	74.0	75.5	76.5	77.0	70 to 80
Stability (kN at 60 °C)	18.5	18.1	18.9	18	Minimum 15
Marshall flow (mm)	2.2	2.3	2.1	2.3	1.5 to 3.0

HD: Hard binder + DBM-II (HiPER-I); HE: Hard binder + EME 2 (HiPER-II); CD: EVA modified binder + DBM-II (HiPER-I); CE: EVA modified binder (V4E13) + EME 2 (HiPER-II);

Table A.2 Performance Test Results of HiPER Bituminous Mixes used in NH18 Test Section

Property of mix	Mix type				Requirement
	HD	HE	CD	CE	
Workability- Gyratory compactor, *(air voids (%) after 45 gyrations)*	3.9	4.9	2.3	2.4	≤ 6 %
Stiffness- Resilient modulus at 35°C, 1 Hz (MPa)	5350	4993	3606	4004	≥ 3500 MPa *(Mixes with modified binders)* ≥4000 MPa (Mixes with unmodified binder)
Rutting (mm) - Wheel tracker, small device at 60°C, 30,000 cycles	4.9	5.1	3.6	4.3	≤ 6 mm
Fatigue- Indirect Tensile Fatigue Test (ITFT) at 25°C, 10^4 cycles	114	118	129	148	Minimum 100 με
Moisture damage - Tensile Strength Ratio (TSR),%	91	94	89	90	≥80 %

HD: Hard binder + DBM-II (HiPER-I); HE: Hard binder + EME 2 (HiPER-II); CD: EVA modified binder + DBM-II (HiPER-I); CE: EVA modified binder (V4E13) + EME 2 (HiPER-II)

A.4 Some Observations on the Construction of Test Sections and their Performance

The summary of the field evaluation conducted after three years of construction on NH18 and two years after construction on NH49 test section is presented below.

- For similar combination of wearing course and granular layers, the central deflection (D_0) and the deflection measured at radial distance of 300 mm from loading plate (D_{300}) measured using Falling Weight Deflectometer (FWD) were observed to be higher in HE (Hard binder + EME2/HiPER-II bituminous mix, D_0: 0.18 to 0.21 mm and D_{300}: 0.10 to 0.11 mm) section compared to that of HD (Hard binder + DBM-II/HiPER-I bituminous mix, D_0: 0.12 to 0.16 mm and D_{300}: 0.08 to 0.09 mm) section.
- D_0 and D_{300} deflections were observed to be smallerin HD (Hard binder + DBM-II/HiPER-I bituminous mix, D_0: 0.12 to 0.16 mm and D_{300}: 0.08 to 0.09 mm) section compared to those of VD (VG40 + DBM-II/HiPER-I bituminous mix, D_0: 0.16 to 0.18 mm and D_{300}: 0.10 to 0.11 mm) section for the same wearing course and granular layers due to higher stiffness of binder.
- The slope (temperature vs deflection) of the sections laid with Hard Binder (HB) was found to be smaller than that of conventional VG40 binder for the same wearing course and granular layers due to higher stiffness of HB binder. It indicates lower temperature sensitivity of HB binder compared to that of VG40 binder.
- For the same wearing course and granular layers, the backcalculated bituminous layer modulus of HE section (Hard binder+EME2/HiPER-II mix, ranging from 3000 to 3900 MPa) was observed to be lower than HD section (Hard binder+DBM-II /HiPER-I bituminous mix, modulus value in the range of 4500 to 4900 MPa) due to the presence of higher binder content in the mix.
- For the same wearing course and granular layers, the backcalculated bituminous modulus of HD section (Hard binder+DBM-II/HiPER-I bituminous mix, ranging from 4500 to 4900 MPa) was observed to be higher than VD section (VG40+DBM-II/HiPER-I bituminous mix, ranging from 3500 to 4500 MPa).
- The roughness of different test sections, after three years of construction for NH18 and two years for NH49, was observed to be in fair to good condition (BI value: 1800 to 2300 mm/km)
- For the similar wearing course, rut depth measured after three years of construction for NH18 and 2 years for NH49, was observed to be smaller in the sections laid with HiPER bituminous mixes (rut depth: 0.6 to 1.09 mm) compared to that of conventional VG40 section (rut depth: 0.85 to 1.43 mm)
- The bituminous cores collected from test section revealed that HiPER bituminous mixes had higher resilient modulus after 2 years (ranging from 2700 to 5600 MPa) than those of conventional bituminous mix prepared with VG40 binder (ranging from 2000 MPa to 2700 MPa).
- The mixes could be compacted to an air void content of 4% or less with tandem vibrating rollers. The rolling sequence of plain, vibration and plain was used effectively for the construction of the test sections.
- HiPER bituminous mixes, being designed as a rich-bottom mixes, can be expected to have a rich binder finish on completion of compaction. Some 'fatting up' is normal and is not an indication of potential problems.

Annexure B

High Performance Binder (HiPB)/High Modulus Bituminous Binder and Mix Specifications adopted by different Countries

The specifications for hard grade/high modulus/High Performance Binders (HiPB) were initially developed by Laboratoire Central des Ponts et Chaussées (LCPC) of France (Delorme et al. 2007). Two different hard grade binders; 10/20 and 15/25 penetration grade binders, were recommended to produce high performance/High Modulus Asphalt (HiMA) mixes. Some other countries adopted the French hard grade binder specifications to produce high performance/ HiMA mixes. The French high performance/hard grade binder specifications are given in **Table B.1**.

Table B.1 French High Performance binder (HiPB) Specifications

Requirement	Property	Hard binders	
		15/25	10/20
Mid temperature consistency	Penetration @ 25°C (0.1 mm)	15 to 25	10 to 20
High temperature consistency	Softening Point (°C)	55 to 71	58 to 78
	Dynamic viscosity @ 60°C (Pa.s)	≥ 550	≥ 700
Resistance to aging	Mass change (%)	≤ 0.5	--
	Retained penetration (%)	≥ 55	---
	Softening point after hardening (°C)	≥ original minimum + 2	
	Increase in softening point (°C)	≤ 8	≤ 10
Construction workability	Kinematic Viscosity @135°C (mm^2/s)	≥ 600	≥ 700

The French specifications for high performance bituminous mixes were developed based on the relationships between the results obtained from the samples prepared in the laboratory and the samples extracted from the field sections. The specifications were given for workability (Gyratory compacter compatibility), rutting, stiffness modulus and fatigue resistance (LPC Bituminous Mixtures Design Guide 2007). The high performance bituminous /HiMA mix specifications for Australia and South Africa were developed by technology transfer concept. Comparative testing was performed with the same mix designs adopted in France and in respective countries using relevant test standards. Based on this exercise, an initial set of data were obtained to benchmark the specifications of high performance bituminous mixes in both the countries. Further, in order to validate these specifications, trial sections were constructed. High performance bituminous / HiMA mix specifications adopted by different countries are given in **Table B.2.**

Table B.2 High Performance Bituminous/HiMA Mix Specifications adopted by different Countries

Country	Property of mix	Test	Standard Method	EME performance requirements	
				Class 1	Class 2
France	Workability	Air voids content (%) after 100 gyrations Gyratory compactor	EN 12697-31	≤ 10	≤ 6
	Moisture damage	Indirect tensile strength ratio using Modified Lottman method	EN 12697-12	≥ 0.7	≥ 0.7
	Rutting	Wheel tracking at 60°C and 30,000 cycles	EN 12697-22	≤ 7.5*	≤ 7.5*
	Stiffness	Two-point bending flexural modulus (MPa) at 15°C, 10 Hz	EN 12697-26 Method A	≥ 14,000	≥ 14,000
	Fatigue	Two-point bending at 25 Hz, 10°C and 10^6 cycles, 50% stiffness reduction must occur at a strain more than	EN 12697-24 Method A	100×10^{-6}	130×10^{-6}
South Africa	Workability	Air voids content (%) after 45 gyrations Gyratory compactor	ASTM D6925	≤ 10	≤ 6
	Moisture damage	Indirect tensile strength ratio using Modified Lottman method	ASTM D4867	≥ 0.8	≥ 0.8
	Rutting	RSST-CH, 55°C, 5000 repetitions (% strain)	AASHTO T320-03	≤ 1.1	≤ 1.1
	Stiffness	Dynamic modulus test at 15°C, 10 Hz, GPa	AASHTO TP 79	≥ 16	≥ 16
	Fatigue	Four-point bending at 10 Hz, 10°C and 10^6 cycles, 50% stiffness reduction must occur at strain greater than	AASHTO T 321	210×10^{-6}	260×10^{-6}
Australia	Workability	Gyratory compactor (% air voids) after 100 gyrations	EN 12697-31	N/A	≤ 6%
	Moisture damage	Indirect tensile strength ratio using Modified Lottman method	AGPT T232	N/A	≥ 0.8
	Rutting	Wheel tracking (large device) at 60°C and 30,000 cycles, mm	AGPT T231	N/A	≤ 6.0
	Stiffness	Four-point bending flexural modulus 15°C, 10Hz, GPa	AGPT/T274	N/A	≥ 14
	Fatigue	Four-point bending at 10Hz, 20°C, and 10^6 cycles, 50% stiffness reduction must occur at strain greater than	AGPT/T274	N/A	150×10^{-6}

** Percentage reduction in total thickness*

Note: *EME (Enrobé à Module Élevé) is a French terminology which translates to high modulus asphalt. There are two classes of EME in the French specifications, EME Class 1 and EME Class 2, with the Class 2 material having significantly higher binder content and superior performance characteristics.*

Annexure C

Test Procedure for determining the Workability of Bituminous Mix

In these guidelines, it is recommended that the workability of HiPER bituminous mixes be assessed by compacting the mix using gyratory compactor (EN 12697-31 standard) at the compaction temperature recommended (Clause 5.3) for the binders under consideration. The air voids present in the bituminous mix shall be determined after applying 45 number of gyrations.

Test Equipment

Gyratory compactor consists of :

- Reaction frame, rotating base, and motor, loading system and pressure gauge.
- Height measuring and recording system.
- Mold and base plate; and specimen extruding device.

The main parameters governing the compaction effort are:

- Vertical pressure : 600 ± 18 kPa.
- Gyration angle of the mold : 1.16 ± 0.02° (internal).
- Gyration rate : 30.0 ± 0.5 gyrations per minute

Test Procedure

- Determine the design bitumen content (corresponding to 3% air void content) by conducting Marshall method of mix design.
- Prepare 150 mm diameter bituminous mix samples with selected aggregate gradation and design bitumen content in gyratory compactor by applying 45 number of gyrations.
- Determine Bulk specific gravity (G_{mb}) and theoretical specific gravity (G_{mm}) of the bituminous mix samples.
- Determine the air voids in the bituminous mix samples and compare with the specification as given in **Table 4.2. Fig. C.1** shows a view of a Gyratory Compactor Equipment.

Fig. C.1 Gyratory Compactor Equipment

Annexure D

Test Procedure for measuring the Resilient Modulus of Bituminous Mix

Resilient modulus (M_r) is an important material input parameter considered in the design of flexible pavements in India (IRC:37). For the purpose of the present guidelines, ASTM D4123-95 procedure is recommended for the measurement of the resilient modulus of HiPER mixes. The resilient modulus is measured by observing the recoverable part of the total strain in the specimen subjected to repeated application of a sequence of haversine load pulse and rest period. The load is applied along the vertical diametrical plane of cylindrical specimen of the mix prepared using selected aggregate gradation, design (optimum) binder content and compacted by applying 75 blows of Marshall compactor on both faces.

Test Equipment

Fig. D.1 shows a typical resilient modulus test set up.

Fig. D.1 Resilient Modulus Test Setup

Test Procedure

Cylindrical samples of 100 mm diameter and 63±1 mm height shall be prepared at optimum binder content and 4% air voids for determining the resilient modulus (M_r) of bituminous mix samples. The test shall be conducted at a temperature of 35°C and at a frequency of 1 Hz (loading time to rest period shall be maintained as 1:9). The environmental chamber of the Universal Testing Machine (UTM 14) shall be used for conditioning the specimens. The samples shall be conditioned at the test temperature for 4 hours prior to the testing. A load in the range of

10% to 20% of the Indirect Tensile Strength (ITS) failure load shall be applied on the specimen and the deformation shall be measured by Linear Variable Differential Transducer (LVDT). The specimen shall be subjected to 100 conditioning cycles initially and another 5 pulse load cycles subsequently.

The average of the resilient modulus values obtained for the last five load cycles is taken as the M_r value of the specimen. Equation D.1 shall be used to calculate the M_r of the specimen.

$$M_r = \frac{P_{cyclic}}{\delta_h * t}(0.27 + \mu) \qquad \text{Eq (D.1)}$$

Where P_{cyclic} = maximum cyclic load applied on the specimen (N); δ_h = horizontal recoverable deformation (mm); t = thickness of the specimen (mm); μ = Poisson's ratio assumed to be 0.35 at 35°C.

Annexure E

Test Procedure for determining the Rutting Performance of Bituminous Mix

The rutting performance of the bituminous mixes is evaluated in the laboratory using dry wheel tracker at a temperature of 60°C according to EN 12697-22 standard.

Equipment and Test Procedure

Fig. E.1 shows the test set up for the evaluation of the rutting potential of bituminous mixes. It consists of an arrangement for the application of a normal load of 700 ±10 N on the specimens. The platform holding the specimens moves back and forth resulting in repeated tracking of a normally loaded wheel over the specimens. The entire test set up is housed in an environmental chamber, in which a constant test temperature is maintained. The specimens of bituminous mixes are to be conditioned for 4 hours before testing them at the test temperature of 60°C. The deformation of the sample is measured using Linear Variable Displacement Transducers (LVDT). One back and forth movement of the wheel is considered as one cycle. The test is to be carried out for 30,000 cycles at a frequency of 20 cycles per minute.

Fig. E.1 Wheel Tracker Test Set up

150 mm diameter specimens of 110-115 mm height shall be prepared using Superpave gyratory compactor to have an air void content of 4.5±0.5%. The compacted specimens shall be sliced to have a height of 50 mm, and the vertical faces of the specimens shall be trimmed to fit into the rigid mould which holds the specimen **(Fig. E.1)**. The progression of rut depth with wheel load applications shall be observed using data acquisition system. The rut depth after 30,000 cycles is recorded and reported.

Annexure F

Test Procedure for determining the Fatigue Performance of Bituminous Mix by Indirect Tensile Fatigue Test

The fatigue performance of bituminous mixes shall be evaluated according to the EN 12697-24:2012 standard.

Equipment and Test Procedure

The test shall be conducted on cylindrical compacted Marshall specimens of 100 mm diameter and 63 mm height, at a temperature of 25°C. **Fig. F.1** shows a typical Universal Testing Machine (UTM) used for conducting Indirect Tensile Fatigue Test (ITFT) on bituminous mix samples. Before conducting the fatigue test, the samples shall be conditioned for a duration of 4 hours at the test temperature of 25°C. The test shall be carried out in control stress mode at three stress levels to be selected based on the recommended indirect tensile strength (ITS) of bituminous mixes measured at 25°C.

A haversine repeated load shall be applied on the specimens with 0.1 sec loading time and 0.4 sec rest time. Two Linear Variable Deformation Transducers (LVDT's) shall be mounted on the Indirect Tensile Fatigue Test (ITFT) jig of UTM (**Fig. F.2)** to measure the horizontal deformation due to the application of loading on the specimen. The loading shall be applied until complete fracture of the specimen. The number of cycles or load applications till complete fracture of specimen is taken as the fatigue life of the specimen. Fatigue performance lines shall be developed for bituminous mixes by plotting a graph between log number of cycles and log initial horizontal strain. The initial horizontal strain is calculated using the load and deformation data collected after 100 load applications. Equations F.1 and F.2 shall be used for the calculation of horizontal tensile stress (σ) and strain (ε_t)

$$\sigma = \frac{2P}{\pi D t} \qquad \text{Eq (F.1)}$$

$$\varepsilon_t = (1 + 3\mu)\frac{\sigma}{M_r} \qquad \text{Eq (F.2)}$$

Where, σ = horizontal tensile stress; P = applied load (N); D = diameter of specimen, mm; t = thickness of specimen, mm; μ = Poisson's ratio; ε_t = horizontal tensile strain; M_r = Resilient modulus measured during the ITFT test after 100 cycles of load. Poisson's ratio (μ) was assumed as 0.35.

Fig. F.1 A Typical Universal Testing Machine

Fig. F.2 ITFT Test Setup

Annexure G

Test Procedure for determining the Moisture Damage of Bituminous Mix

The moisture damage of the mixes is evaluated according to the AASHTO T283 standard.

Equipment and Test Procedure

Cylindrical specimens of 101±1 mm of diameter and 63 ±1 mm of height shall be prepared at the design binder content and shall becompacted to an air void content of 4.0% since the rich bitumen mixes shall be compacted to an initial air void content of 4.0% as per the recommendations given in this guideline. The specimens shall be divided into two sets; unconditioned (dry) and conditioned (wet). Six specimens shall be prepared for each bituminous mix, with three for each test condition. To condition the specimens, a target degree of saturation of 70-80% shall be achieved. This involves placing specimens in a vacuum container, maintaining a 25 mm distance from the container bottom using a perforated spacer. The container shall be filled with potable water, and a vacuum pressure of 13-67 kPa shall be applied for 5-10 minutes. Degree of saturation shall be determined by comparing water volume absorbed to air void volume. Once the target saturation is achieved, specimens shall be sealed in plastic bags containing 10±0.5 ml of water and then placed in a water chamber at 60±0.5°C for 24±1 hours, followed by 25±0.5°C for 2 hours. Indirect Tensile Strength (ITS) test shall be conducted on both unconditioned and conditioned specimens at 25°C, and the Tensile Strength Ratio (TSR) shall be calculated using Equation G.1.

$$\text{Tensile Strength Ratio (TSR)} = \frac{\text{Average ITS of conditioned specimen}}{\text{Average ITS of unconditioned specimen}} \times 100 \qquad \text{Eq (G.1)}$$

Annexure H

Selection of Mixing and Compaction Temperatures of Binders

Equiviscous temperature method is commonly used to determine laboratory mixing and compaction temperatures of binders. The intention behind this method is to produce similar coating and lubricating ability of different binders and to normalize the effect of binder stiffness on the volumetrics of bituminous mixes. In this method, the viscosity of the binder is determined at two test temperatures by establishing a relationship between temperature and viscosity. The mixing and compaction temperatures are determined from the viscosity-temperature relationship for the viscosity ranges of 0.17 ± 0.02 Pa-s and 0.28 ± 0.03 Pa-s recommended for mixing and compaction, respectively.

It is important to understand that the High Performance (HiPB) bituminous binders can also be produced through modification approach as discussed previously in the document. These HiPBs can frequently result in unusually high equiviscous mixing and compaction temperatures, often over 350°F (177°C). High mixing temperatures can introduce several issues, including the binder degradation and increased stiffening (aging) of the binder. Moreover, higher compaction temperatures can pose challenges during the compaction of bituminous mix in the field. The research outlined in NCHRP Report 648, "Mixing and Compaction Temperatures of Asphalt Binders in Hot-Mix Asphalt," suggests that modified binders should be tested following one of two procedures: Dynamic Shear Rheometer (DSR) Phase Angle Procedure or the DSR Steady Shear Flow Procedure.

The DSR Phase Angle Procedure is performed by conducting a shear frequency sweep at a strain of 12%, from 0.1 to 100 radians per second (rad/s) at a minimum of three temperatures, developing a master curve at 176°F (80°C), and determining the frequency where the phase angle equals 86 degrees. This frequency is then input into below equations to calculate mixing and compaction temperatures.

$$\text{Mixing temperature (°F)} = 310\ w^{-0.01}$$

$$\text{Compaction temperature (°F)} = 300\ w^{-0.0012}$$

Where, w is frequency in rad/sec.

The DSR Steady Shear Flow Procedure uses a shear stress sweep from 50 to 1000 Pa at a minimum of three test temperatures to determine the steady state viscosity. This viscosity is then plotted as a function of temperature, from which the mixing and compaction temperatures are derived. The mixing and compaction temperatures are selected corresponding to the viscosity ranges of 0.17 ± 0.02 Pa. s and 0.35 ± 0.03 Pa.s, respectively.

Annexure I

Illustration of Structural Design of Bituminous Pavement with HiPER Bituminous Mix Base Layer

For illustrating the design of bituminous pavements with HiPER bituminous base layer, the following design data were taken from example II.3 of IRC:37.

Design traffic	: 131 msa
Effective CBR of the subgrade	: 7%
Reliability	: 90%

Solution:

Three combinations of pavement with (a) conventional DBM-II mix (DBM-II aggregate gradation and VG40 bitumen), (b) HiPER bituminous mix with refinery binder/ unmodified bitumen (DBM-II/ EME aggregate gradation and HB binder) and (c) HiPER bituminous mix with modified bitumen (DBM-II/EME aggregate gradation and polymer modified binder), used in base layer, have been considered for this example.

Details of the inputs considered for the analysis and design of the three pavement sections are given in **Table I.1.** The same effective binder volume of 11.5% was considered for all the three mixes. It may be noted that, for a realistic pavement design exercise, the effective binder contents at which 3% air void content is achieved may be different for different mixes. For the given design traffic, effective subgrade modulus, the base bituminous layer thickness was varied keeping the thicknesses of surface layer, granular base and subbase layers the same for the three types of pavements and the vertical compressive strain on subgrade and the horizontal tensile strain at the bottom of the bituminous base layer were computed using IITPAVE software. The design base layer thicknesses and the corresponding computed strain values are given in **Table I.1.** For the purpose of this example, the elastic (resilient) modulus values of the base bituminous layer (which were the moduli values used for the surface/wearing course also). The elastic moduli of subgrade and granular layers were selected as per the guidelines given in IRC:37. As can be seen from **Table I.1** that the requirement of base layer thickness is reduced with the use of HiPER bituminous mixes in the base layer.

Table I.1 Details of Structural Design with three different Base Layer Bituminous Mixes

Design Parameter	Bituminous base layer with		
	Conventional mix (DBM-II + VG40 bitumen)	HiPER mix (HiPER gradation-I/II + refinery binder/ unmodified bitumen)	HiPER mix (HiPER gradation-I/II + modified bitumen)
Input Data			
Effective resilient modulus of Subgrade, MPa	62	62	62
Resilient modulus of the granular layer, MPa	200	200	200
Resilient modulus of bituminous mixes at 35 °C, MPa	3000	4000	3500
Volume of air voids (V_a), %	3	3	3
Effective volume of bitumen (V_{beff}), %	11.5	11.5	11.5
Allowable vertical compressive strain on subgrade, x (10^{-06})	301	301	301
Allowable horizontal tensile strain at the bottom of bituminous layer, x (10^{-06})	150*	153.5#	158.1#
Design Parameters (Output Data)			
Wearing course thickness, mm	40	40	40
Bituminous base course thickness, mm	150	120	125
Granular base thickness, mm	250	250	250
Granular subbase thickness, mm	230	230	230
Computed vertical compressive strain, x (10^{-06})	244	265	266
Computed horizontal tensile strain, x (10^{-06})	146	149	155

**Calculated using equation 6.1;*

 # Calculated using equation 6.2

REFERENCES

- AASHTO T283, (2011). 'Standard Method of Test for Resistance of Compacted Hot Mix Asphalt (HMA) to Moisture- Induced Damage'. American Association of State Highway and Transportation Officials. Washington, DC.
- AASHTO, T. 245 (2015) 'Standard Method of Test for Resistance to Plastic Flow of Asphalt Mixtures using Marshall Apparatus'. American Association of State Highway and Transportation Officials, Washington, DC.
- AGPT/T231, 'Deformation Resistance of Asphalt Mixtures by The Wheel Tracking' Test. Austroads, (2006).
- AGPT/T232: 'Stripping Potential of Asphalt: Tensile Strength Ratio', Austroads. (2007).
- AGPT/T274: 'Characterisation of Flexural Stiffness and Fatigue Performance of Bituminous Mixes', Austroads. (2016).
- Arunkumar Goli, (2022), 'Development and Performance Evaluation of High Modulus Asphalt Mixes', PhD Thesis, IIT Kharagpur.
- ASTM D 2041 (2011), 'Standard Test Method for Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures'. ASTM International West Conshohocken, PA.
- ASTM D 6927 (2015), 'Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures'. ASTM International, USA.
- ASTM D 2872 (2019), 'Standard Test Method for Effect of Heat and Air on a moving Film of Asphalt' (Rolling Thin Film Oven Test). ASTM International, USA.
- ASTM D 4123 (1995), 'Standard Test Method for Indirect Tension Test for Resilient Modulus of Bituminous Mixtures'. ASTM International, USA
- ASTM D 6931 (2017), 'Standard Test Method for Indirect Tensile (IDT) Strength of Asphalt Mixtures'. ASTM International, Pennsylvania 19428-2959, USA.
- Baditha A.K (2023), 'Laboratory and Field Performance Evaluation of High Modulus Asphalt Mixes for High Volume Roads', PhD Thesis, IIT Kharagpur.
- IS:1203 (1978), 'Methods of Testing Tar and Bituminous Materials', Determination of Penetration, Bureau of Indian Standards, New Delhi
- IS:1205 (1978), 'Methods of Testing Tar and Bituminous Materials', Determination of Softening Point, Bureau of Indian Standards, New Delhi
- IS:1206-03 (1978), 'Methods of Testing Tar and Bituminous Materials', Determination of Dynamic and Kinematic Viscosity, Bureau of Indian Standards, New Delhi
- IS:15462 (2019), 'Polymer Modified Bitumen (PMB)-Specification' (First Revision). Bureau of Indian Standards, New Delhi

- IS:2386 (Part I) (1963), 'Methods of Test for Aggregates for Concrete', Part I. Particle Shape and Size, Bureau of Indian Standards, New Delhi.
- IS:2386 (Part III) (1963), 'Methods of Test for Aggregates for Concrete', Part III Mechanical Properties, Bureau of Indian Standards, New Delhi.
- IS:2386 (Part IV) (1963), 'Methods of Test for Aggregates for Concrete', Part IV. Mechanical Properties, Bureau of Indian Standards, New Delhi.
- IS:2386 (Part V) (1963), 'Methods of Test for Aggregates for Concrete, Part V Soundness, Bureau of Indian Standards, New Delhi.
- IS:6241 (1971), 'Method of Test for Determination of Stripping Value of Road Aggregates', Bureau of Indian Standards, New Delhi.
- Brosseaud, Y., Farcas, F., & Mouillet, V. (2012), 'High Modulus Asphalt Mixes with High Rate of RA: what does it happen'? Congrès Eurobitume Eurasphalt, EE2012.
- Chakkoth, U., Ravindran, P., & Krishnan, J. M. (2017), 'Influence of Viscosities of PDA Pitch and Flux on Blended Bitumen Viscosity'. International Conference on Airfield and Highway Pavements, 2017, 225-235.
- Corbett, L. W. (1984), 'Refinery Processing of Asphalt Cement'. Transportation Research Record, 999, 1-6.
- Corte, J. F. (2001), 'Development and uses of Hard-Grade Asphalt and of High-Modulus Asphalt Mixes in France'. Transportation Research Circular, 503, 12-31.
- Delorme, J. L., De la Roche, C., & Wendling, L. (2007), 'LPC Bituminous Mixtures Design Guide'. Laboratoire Central des Ponts et Chaussées.
- Dias, M., Petho, L., Denneman, E., & Beecroft, A. (2017), 'High Modulus High Fatigue Resistance Asphalt (EME2) Technology Transfer' p. 48 (Report No. AP-T323-17).
- EN 12697-12 (2018), Bituminous Mixtures: Test Methods: Part 12: 'Determination of the Water Sensitivity of Bituminous Specimens'. European Committee for Standardization.
- EN 12697-22 (2019), 'Bituminous Mixtures: Test Methods: Part 22: Wheel Tracking'. European Committee for Standardization.
- EN 12697-24 (2012), 'Bituminous Mixtures. Test Methods for Hot Mix Asphalt–Part 24: Resistance to Fatigue'. Annex E “Indirect Tensile Test Cylindrical. Shaped Specimens”. European Committee for Standardization.
- EN 12697-24 (2019), 'Bituminous Mixtures: Test Methods: Part 24: Resistance to Fatigue. European Committee for Standardization.

- EN 12697-25 (2019), 'Bituminous Mixtures: Test Methods: Part 25: Cyclic Compression Test'. European Committee for Standardization.
- EN 12697-26 (2019), 'Bituminous Mixtures: Test Methods: Part 26: Stiffness'. European Committee for Standardization.
- EN 12697-31 (2019), 'Bituminous Mixtures. Test Methods for Specimen Preparation by Gyratory Compactor'. European Committee for Standardization.
- Final report, 'Development of High Modulus Asphalt (HiMA) Mixes for Indian Highways' Submitted to NHAI, New Delhi (2022).
- Goli, A., Baditha, A., Muppireddy, A. R. (2021), 'High Modulus Bituminous Binders and Mixes for High Volume Roads: A Review'. Journal of Indian Highways, New Delhi, 49(03),19-25.
- Hernandez, M. I. G. (2015), 'High Modulus Asphalt Concrete: A Long-Life Asphalt Pavement'. Journal of Civil & Environmental Engineering, 5(5), 1.
- IRC: 37 (2018), 'Guidelines for the Design of Flexible Pavements', 4th Revision, Indian Roads Congress, New Delhi, India.
- Ishai, I., & Tuffour, Y. A. (1987), 'The Use of Propane-Precipitated Asphalt (PPA) in Bituminous Paving Mixtures' (with discussion). In Association of Asphalt Paving Technologists Proceedings, 56, 599-631.
- Moreno-Navarro, F., Sol-Sánchez, M., Rubio-Gámez, M. C., & Segarra-Martínez, M. (2014),. 'The Use of Additives for the Improvement of the Mechanical Behavior of High Modulus Asphalt Mixes'. Construction and Building Materials, 70, 65-70.
- MoRTH (2013), 'Specifications for Road Works and Bridges'. Ministry of Road Transport and Highways, 5th Edition, New Delhi, India.
- MS-2 (2015), 'Manual Series No -2-Asphalt Mix Design Methods', 7th Edition, Asphalt Institute, USA.
- Sanders, P. J., & Nunn, M. E. (2005), 'The Application of Enrobe a Module Eleve in Flexible Pavements'. Crowthorne: Transport Research Laboratory.
- Serfass, J. P., Bense, P., & Pellevoisin, P. (1996), 'Properties and New Developments of High Modulus Asphalt Concrete'. In 8th International Conference on Asphalt Pavements, Federal Highway Administration, 1, 325-333.

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